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Title: UV Extinction Properties of Carina Nebular Dust
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1.0 Introduction

Trumpler 16 is a very young open cluster which contains ultra-luminous object η Car and several O3 stars. The cluster gas exhibits peculiar motions of more than 500 km/s (see, Walborn et al 1984), and the dust has a large and variable R(V) = A(V)/E(B-V). In this report, I present UV observations of the Tr 16 dust, demonstrate systematic changes in the extinction curves which occur as one samples deeper into the cloud, and isolate the signature of the UV extinction of the dust within the molecular cloud.

2.0 Observations

Table 1 lists the program stars which have IUE observations. These were selected to lie in groups within a few arc minutes of each other on the sky. The names given in Table 1 are from The et al (1980). The spectral types given in parenthesis are from classifications of the low dispersion IUE spectra. Some of the spectra were difficult to classify because the interstellar lines were broad enough to contaminate some important stellar lines, such as Si III λ1300. The spectra were matched to unreddened standards to produce extinction curves (see Fitzpatrick and Massa 1990, FM).

The extinction curves for the program stars are shown in Figure 1. These were derived exactly as described by FM. Available IR photometry (Tapia et al 1988) is included and the curves are compared to a family of CCM (Cardelli et al 1989) curves, with R(V) = 2, 3, 4, and 5.

3.0 Analysis

Figure 2 shows FM fits to the UV portions of the curves, where the fitting function is given by

$$k(x-\lambda) = c_1 + c_2 x + c_3 D(\gamma, x_0; x) + c_4 F(x) ,$$

where $x = \lambda^{-1}$, $D(\gamma, x_0; x)$ is a Drude profile, and $F(x)$ is a function which is zero for $x < 5.9\mu^{-1}$ (see FM for details). Table 2 lists the parameters derived from the fitting procedure. Relationships among the various observables are shown in Figure 3 Figure 3a shows the relationship between IR extinction and E(B-V). This relationship shows that the value of R increases as more and more of the dust associated with the cloud affects the line of sight. This same effect was already discussed by Tapia et al. Figure 3b shows an apparent relationship between the bump position, x_0, and E(B-V). However, this may be due to a bias in the fitting routine. This is because, as Figure 3c demonstrates, the slope of the UV extinction decreases with E(B-V). This relationship could influence the nonlinear fit of x_0. Figure 3d shows the relationship between the offset and slope of the UV fit, c_1 and c_2, for the cluster stars (crosses), compared to the same parameters derived from a diverse sample of stars studied by Fitzpatrick and Massa (1988) (triangles). Notice that the cluster stars seem to lie systematically beneath the line derived for the Fitzpatrick and Massa sample.

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To isolate the Tr 16 molecular cloud extinction, and to eliminate the foreground extinction, differential extinction curves were formed by using the differences between the color excesses of heavily reddened stars and lightly reddened stars within 2' on the sky of them. All of the stellar pairs with $\Delta E(B-V) > 0.1$ mag were summed to form a mean Tr 16 molecular cloud extinction curve.

Figure 4 shows the resulting ***differential*** extinction curve for Tr 16 dust. This curve is affected only by dust within the Tr 16 star-forming cloud. The pairs of stars used to produce the curve are: Tr16-14&13, 15&13, 17&94, 21&20, 7&9, 8&9, and 73&115. The only heavily reddened star not included was Tr16-76. Unlike the other cluster stars, this object has a relatively high FUV extinction. The mean differential curve is compared to CCM curves with R = 2, 3, 4, 5, and 6.

Finally, Figure 5 compares the differential curve for Tr16 with that of the Orion star NU Ori given by FM. The 2 curves are essentially indistinguishable.

4.0 Conclusion

The extinction curve for ***dust inside the Tr 16 molecular cloud*** closely resembles a CCM R = 5 curve, and is almost idential to that of the Orion molecular cloud, as sampled by NU Ori. The NU Ori curve does not have to be corrected for foreground extinction because it is very small along its line of sight compared to the extinction caused by the Orion cloud itself. In conclusion, the observations shows that dust in another spiral arm demonstrates the same morphological behavior as dust in the local clouds used to derive the CCM relationships. This finding was n presented at the 181-st meeting of the AAS in Phoenix, and is currently being incorporated into a larger paper in collaboration with Dr. Jason Cardelli at the University of Wisconsin. Cardelli has obtained IUE observations of main sequence B and late O stars in the young cluster NGC 6611, and has come to similar conclusions. We have decided, therefore, to combine the observations of the 2 clusters into a single presentation.

References

Cardelli, J.A., Clayton, G.C. and Mathis, J.S. 1989 ApJ 345, 245
Fitzpatrick, E.L. and Massa, D. 1988 ApJ 328, 734
Fitzpatrick, E.L. and Massa, D. 1990 ApJS 72, 163
Massa, D. and Savage, B.D. 1984 ApJ 279, 310
Tapia, M., Roth, M., Marraco, H. and Ruiz, M.T. 1988, MNRAS 232, 661
The, P.S., Bakker, R. and Antalova, A. 1980, A&AS, 41, 93
Walborn, N.R., Heckathorn, J.N., and Hesser, J.E. 1984 ApJ 276, 524

Table 1: Program Stars

Name	Sp Ty	V	B-V	E(B-V)	UV Match
Tr16- 8	B1.5Vb	10.90	0.14	0.42	B0.5 V
Tr16-13	(B1)	10.76	0.22	0.50	B0.5 V
Tr16-14	(O-B0)	11.50	0.42	0.72	O9.5 V
Tr16-15	(B0.5)	11.28	0.41	0.69	B0.5 V
Tr16-17	(B0)	11.01	0.24	0.54	B0 V
Tr16-20	B1 V	10.20	0.08	0.34	B1 V
Tr16-21	(B0)	10.93	0.47	0.77	B0 V
Tr16-22	(O7)	11.01	0.49	0.81	O7 V
Tr16-23	O7 Vn	9.97	0.38	0.70	O7 V
Tr16-24	(B1)	11.58	0.16	0.42	B1 V
Tr16-27	(B1)	11.06	0.14	0.40	B1 V
Tr16-33	(B2)	11.83	0.27	0.51	B2 V
Tr16-73	(B1)	11.90	0.42	0.68	B1 V
Tr16-74	(B1)	11.70	0.27	0.53	B1 V
Tr16-76	(B0)	11.19	0.42	0.70	B0.5 V
Tr16-94	B1 Vn	9.86	0.14	0.40	B1 V
Tr16-115	O9 V	10.15	0.16	0.46	O9.5 V

Table 2: Fit Parameters

Star	Match	x_0	γ	c_1	c_2	c_3	c_4
Tr16- 8	B0.5 V	4.601	0.882	0.057	0.523	2.344	0.301
Tr16-13	B0.5 V	4.570	1.066	-0.150	0.601	2.932	0.140
Tr16-14	O9.5V	4.585	1.193	0.036	0.507	2.971	0.155
Tr16-15	B0.5 V	4.589	1.024	0.428	0.427	2.556	0.285
Tr16-17	B0 V	4.607	1.000	0.042	0.553	1.979	0.456
Tr16-20	B1 V	4.597	0.864	0.391	0.600	2.533	0.354
Tr16-21	B0 V	4.599	0.926	0.941	0.311	2.058	0.160
Tr16-22	O7 V	4.596	1.017	0.647	0.338	2.589	0.166
Tr16-23	O7 V	4.567	0.806	0.531	0.467	1.554	0.169
Tr16-24	B1 V	4.604	0.974	0.290	0.511	2.362	0.354
Tr16-27	B1 V	4.594	0.881	-0.631	0.632	2.711	0.340
Tr16-33	B2 V	4.598	0.891	0.396	0.511	2.348	0.288
Tr16-73	B1 V	4.588	0.855	0.366	0.435	2.120	0.306
Tr16-74	B1 V	4.580	0.793	0.188	0.466	1.791	0.246
Tr16-76	B0.5 V	4.572	0.957	0.132	0.606	2.565	0.435
Tr16-94	B1 V	4.591	0.813	-0.670	0.846	1.793	0.897
Tr16-115	O9.5V	4.583	0.909	-0.034	0.579	2.228	0.367

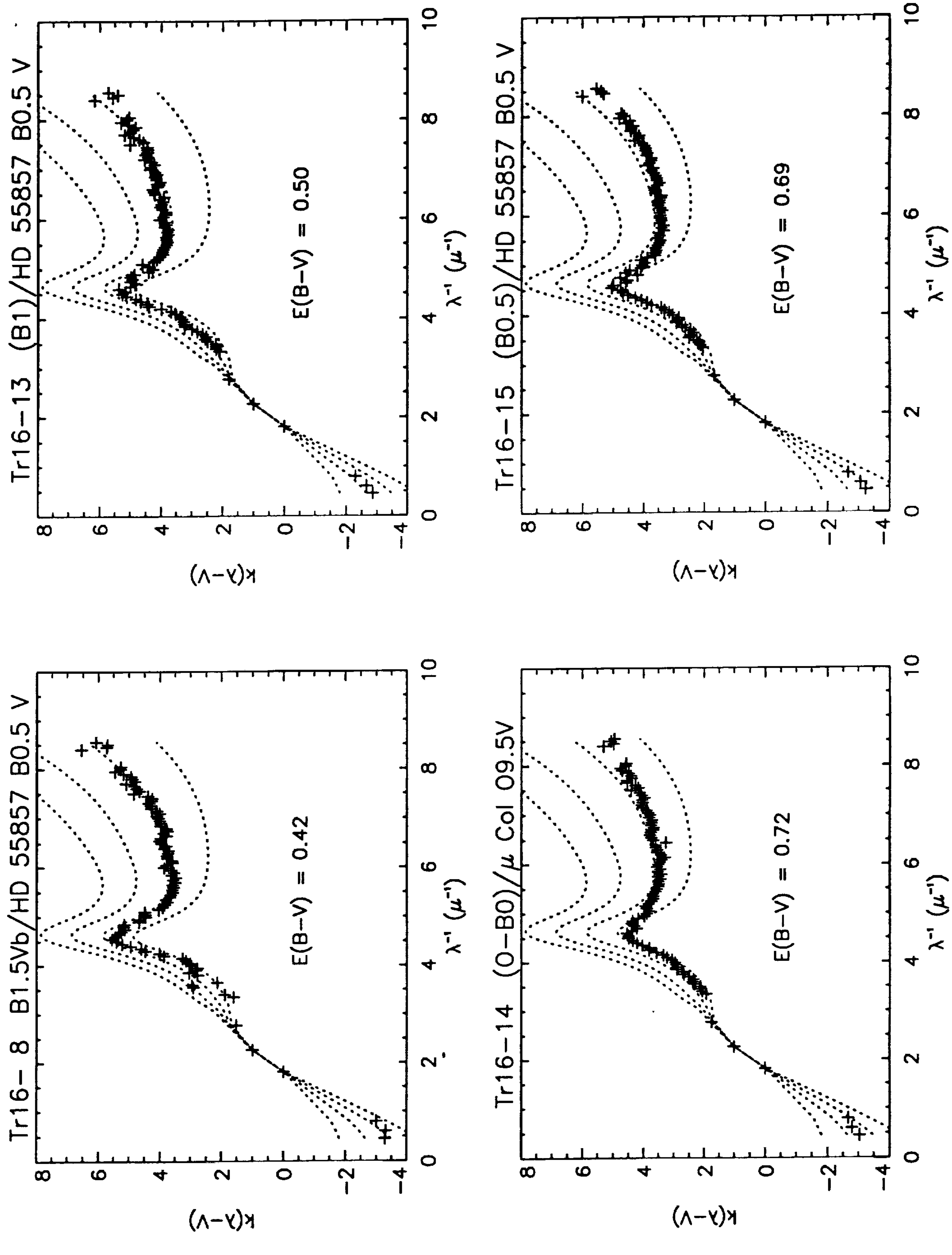

Tr16−13 (B1)/HD 55857 B0.5 V
E(B−V) = 0.50
Tr16−15 (B0.5)/HD 55857 B0.5 V
E(B−V) = 0.69
Tr16− 8 B1.5Vb/HD 55857 B0.5 V
E(B−V) = 0.42
Tr16−14 (O−B0)/μ Col O9.5V
E(B−V) = 0.72
k(λ−V)
λ⁻¹ (μ⁻¹)

Fig 1

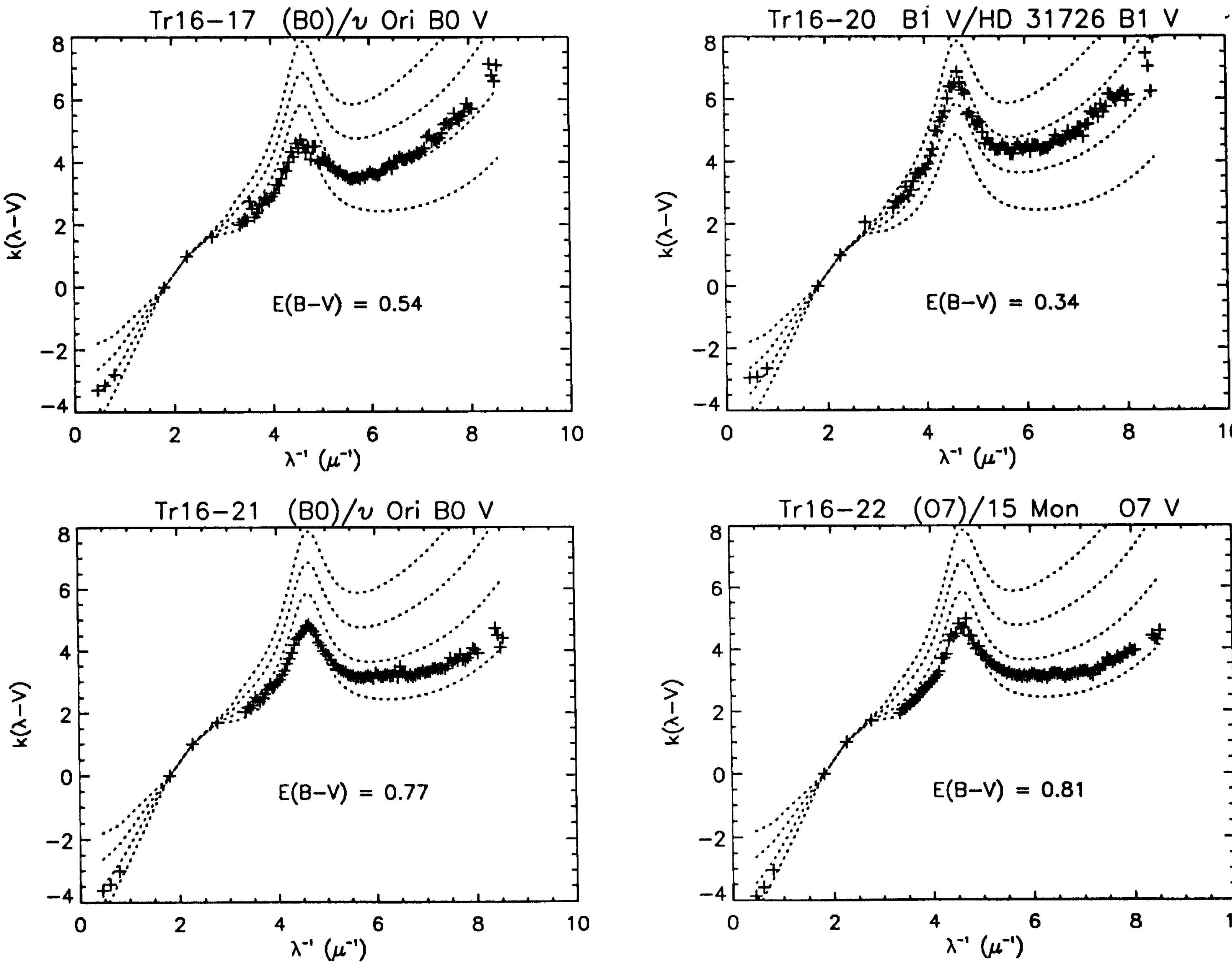

Tr16-17 (B0)/υ Ori B0 V
E(B-V) = 0.54
Tr16-20 B1 V/HD 31726 B1 V
E(B-V) = 0.34
Tr16-21 (B0)/υ Ori B0 V
E(B-V) = 0.77
Tr16-22 (O7)/15 Mon O7 V
E(B-V) = 0.81
k(λ-V)
λ⁻¹ (μ⁻¹)

Fig 1 (cont)

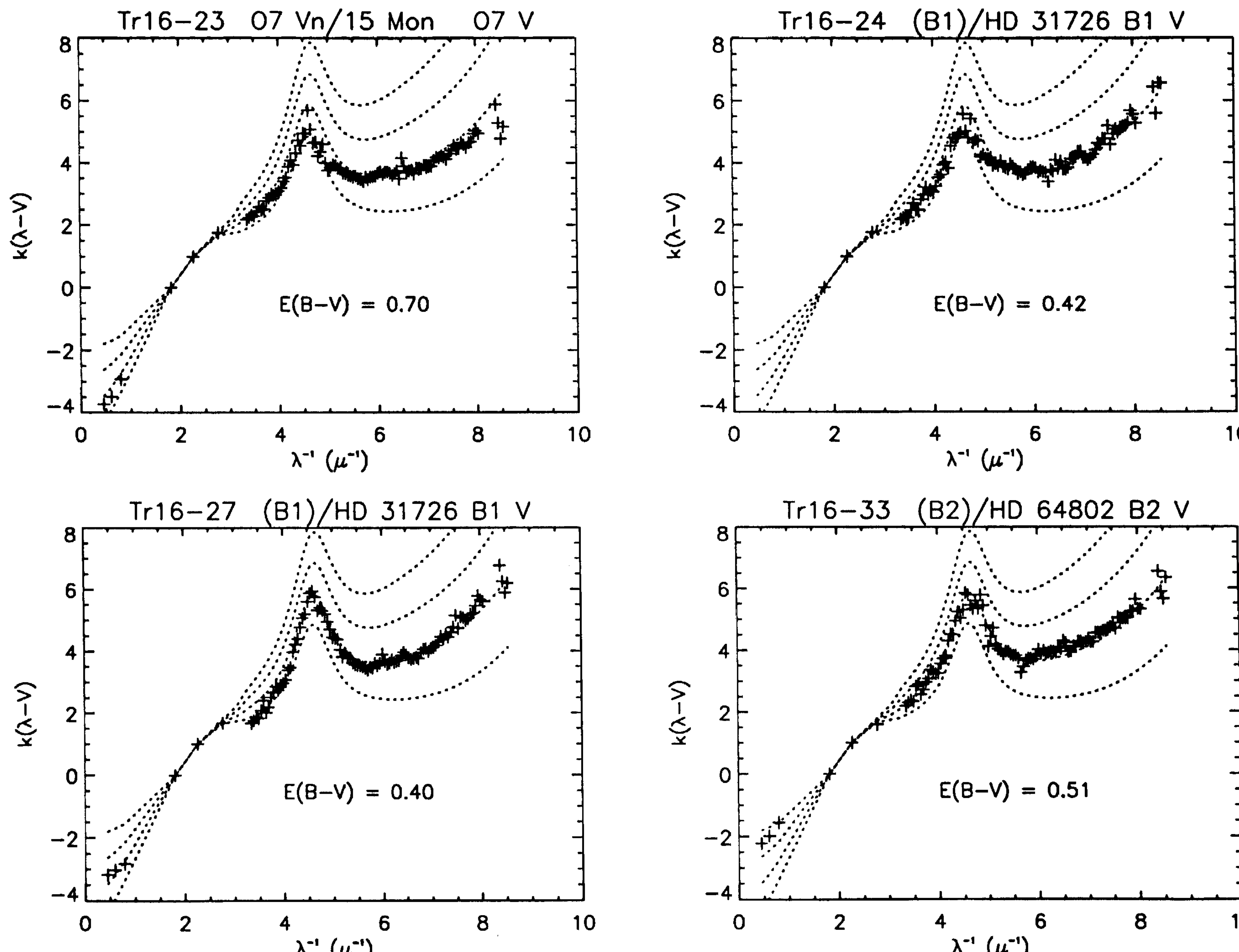
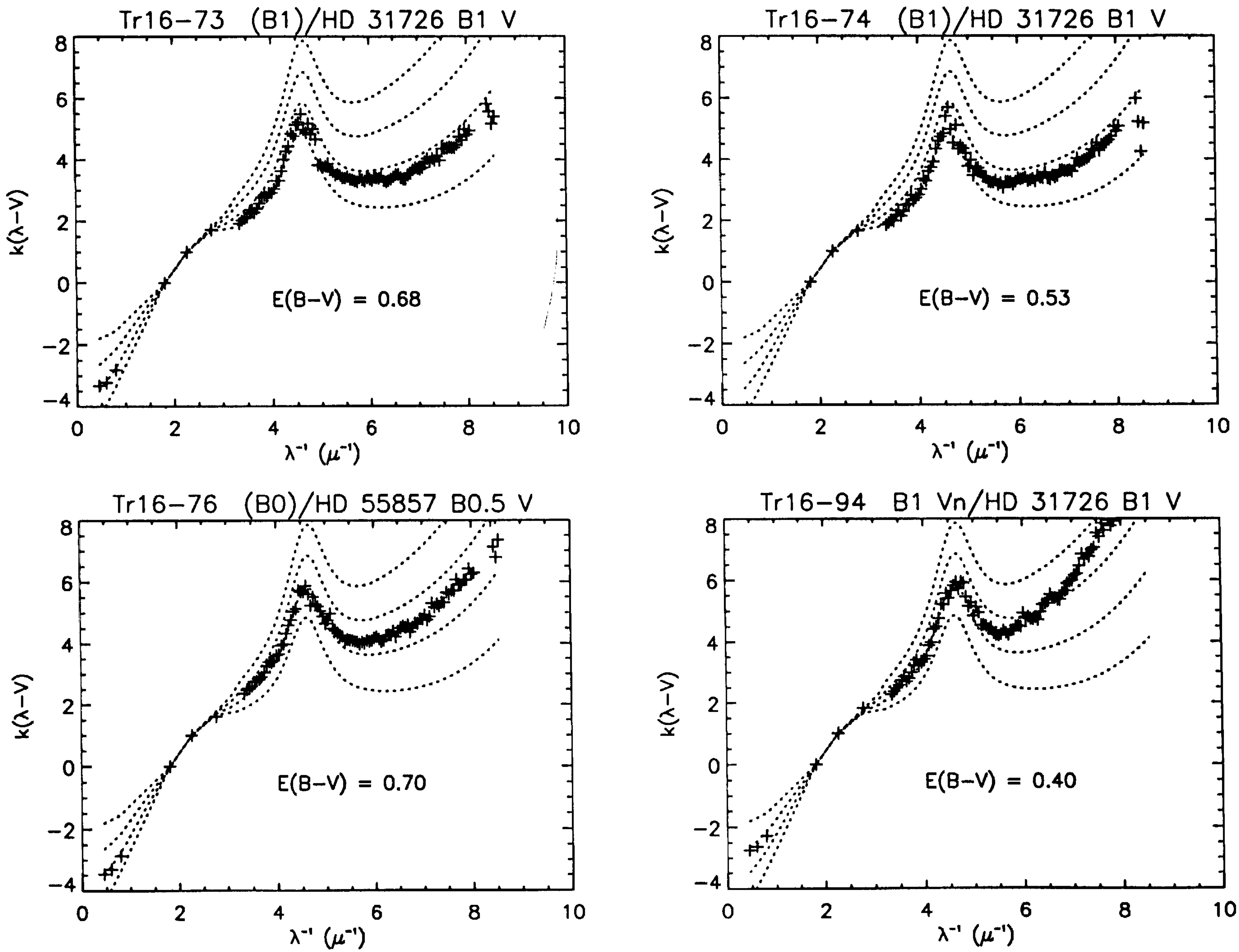

Tr16−23 O7 Vn/15 Mon O7 V
E(B−V) = 0.70
Tr16−24 (B1)/HD 31726 B1 V
E(B−V) = 0.42
Tr16−27 (B1)/HD 31726 B1 V
E(B−V) = 0.40
Tr16−33 (B2)/HD 64802 B2 V
E(B−V) = 0.51
k(λ−V)
λ⁻¹ (μ⁻¹)

Fig 1 (cont)



Tr16-73 (B1)/HD 31726 B1 V
E(B-V) = 0.68
Tr16-74 (B1)/HD 31726 B1 V
E(B-V) = 0.53
Tr16-76 (B0)/HD 55857 B0.5 V
E(B-V) = 0.70
Tr16-94 B1 Vn/HD 31726 B1 V
E(B-V) = 0.40
k(λ-V)
λ⁻¹ (μ⁻¹)

Fig 1 (cont)

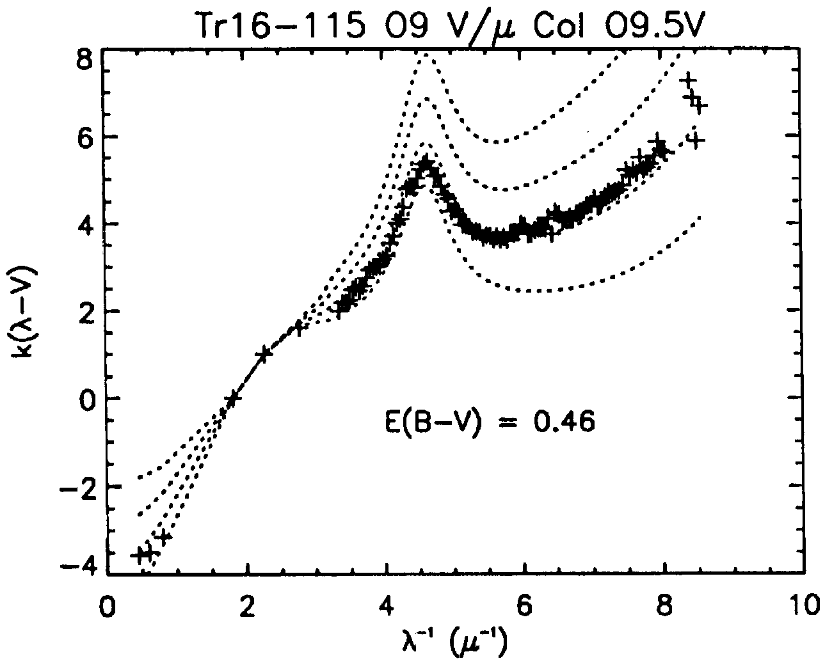


Fig 1 (Cont)

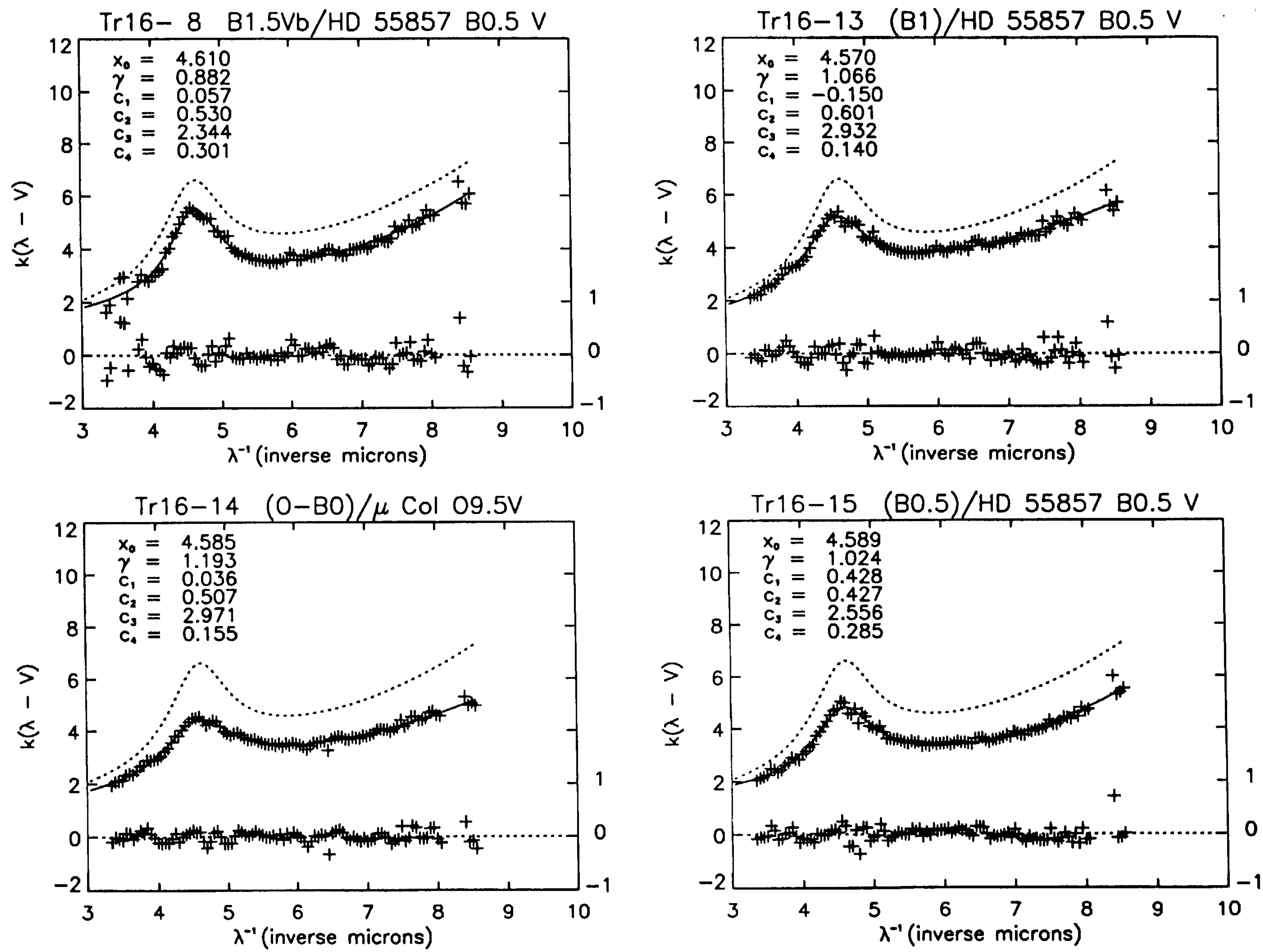

Tr16- 8 B1.5Vb/HD 55857 B0.5 V
x_0 = 4.610
γ = 0.882
c_1 = 0.057
c_2 = 0.530
c_3 = 2.344
c_4 = 0.301
Tr16-13 (B1)/HD 55857 B0.5 V
x_0 = 4.570
γ = 1.066
c_1 = -0.150
c_2 = 0.601
c_3 = 2.932
c_4 = 0.140
Tr16-14 (O-B0)/μ Col O9.5V
x_0 = 4.585
γ = 1.193
c_1 = 0.036
c_2 = 0.507
c_3 = 2.971
c_4 = 0.155
Tr16-15 (B0.5)/HD 55857 B0.5 V
x_0 = 4.589
γ = 1.024
c_1 = 0.428
c_2 = 0.427
c_3 = 2.556
c_4 = 0.285
$k(\lambda - V)$
λ^{-1} (inverse microns)

Fig 2

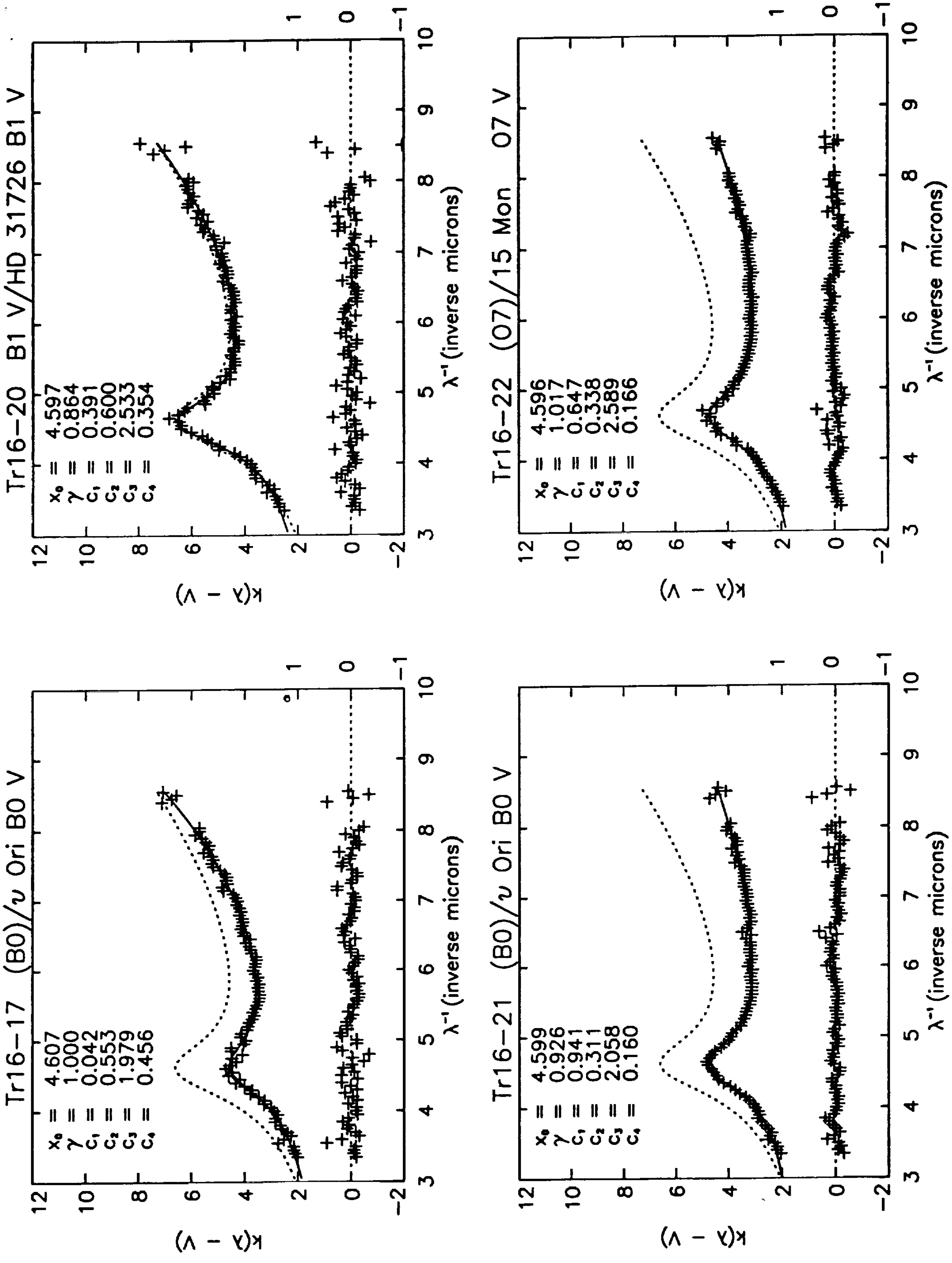

Tr16−17 (B0)/υ Ori B0 V
x₀ = 4.607
γ = 1.000
c₁ = 0.042
c₂ = 0.553
c₃ = 1.979
c₄ = 0.456
Tr16−20 B1 V/HD 31726 B1 V
x₀ = 4.597
γ = 0.864
c₁ = 0.391
c₂ = 0.600
c₃ = 2.533
c₄ = 0.354
Tr16−21 (B0)/υ Ori B0 V
x₀ = 4.599
γ = 0.926
c₁ = 0.941
c₂ = 0.311
c₃ = 2.058
c₄ = 0.160
Tr16−22 (O7)/15 Mon O7 V
x₀ = 4.596
γ = 1.017
c₁ = 0.647
c₂ = 0.338
c₃ = 2.589
c₄ = 0.166
k(λ − V)
λ⁻¹ (inverse microns)

Fig 2 (cont)

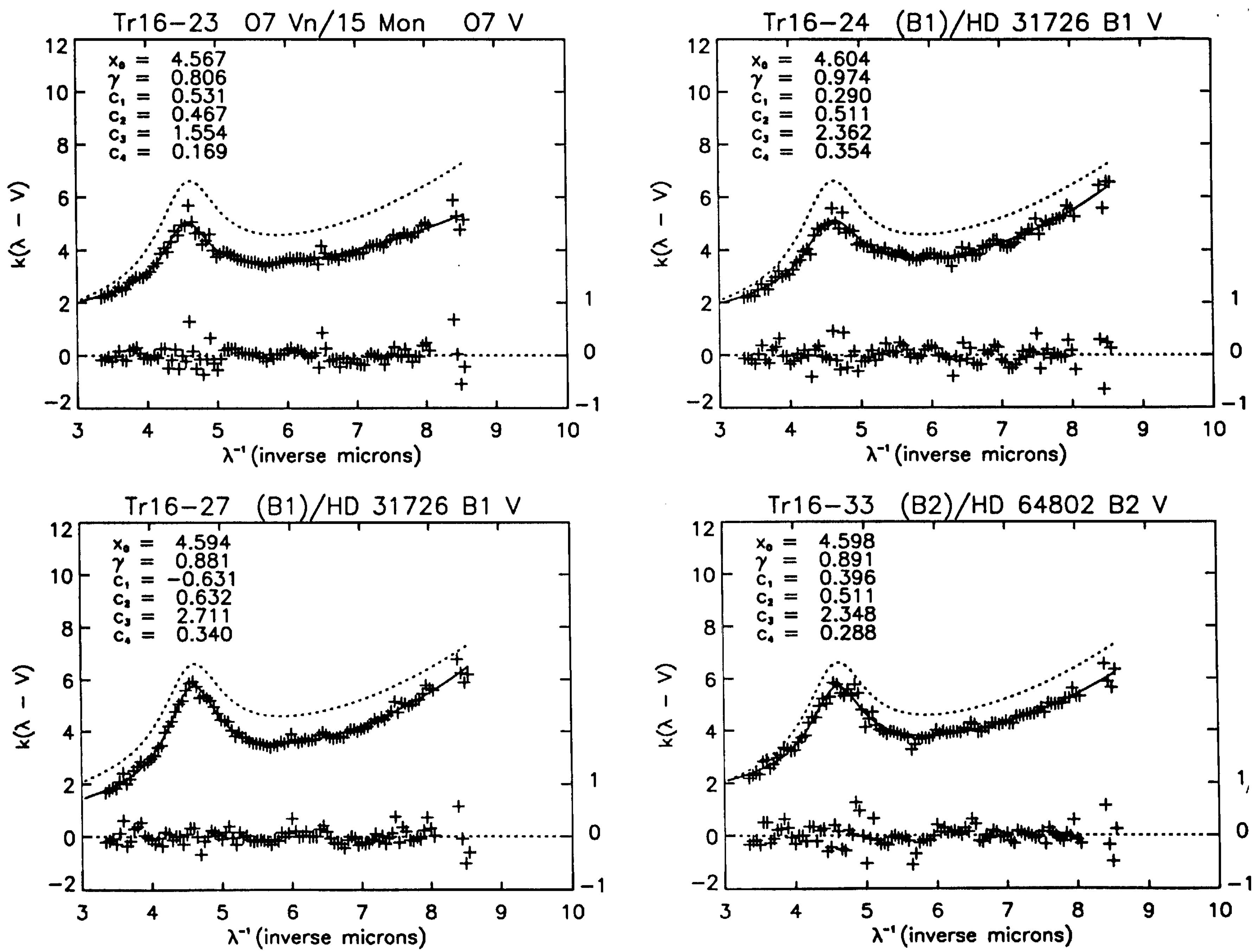

Tr16−23 O7 Vn/15 Mon O7 V
x0 = 4.567
γ = 0.806
c1 = 0.531
c2 = 0.467
c3 = 1.554
c4 = 0.169
Tr16−24 (B1)/HD 31726 B1 V
x0 = 4.604
γ = 0.974
c1 = 0.290
c2 = 0.511
c3 = 2.362
c4 = 0.354
Tr16−27 (B1)/HD 31726 B1 V
x0 = 4.594
γ = 0.881
c1 = −0.631
c2 = 0.632
c3 = 2.711
c4 = 0.340
Tr16−33 (B2)/HD 64802 B2 V
x0 = 4.598
γ = 0.891
c1 = 0.396
c2 = 0.511
c3 = 2.348
c4 = 0.288
k(λ − V)
λ⁻¹ (inverse microns)

Fig 2 (cont)

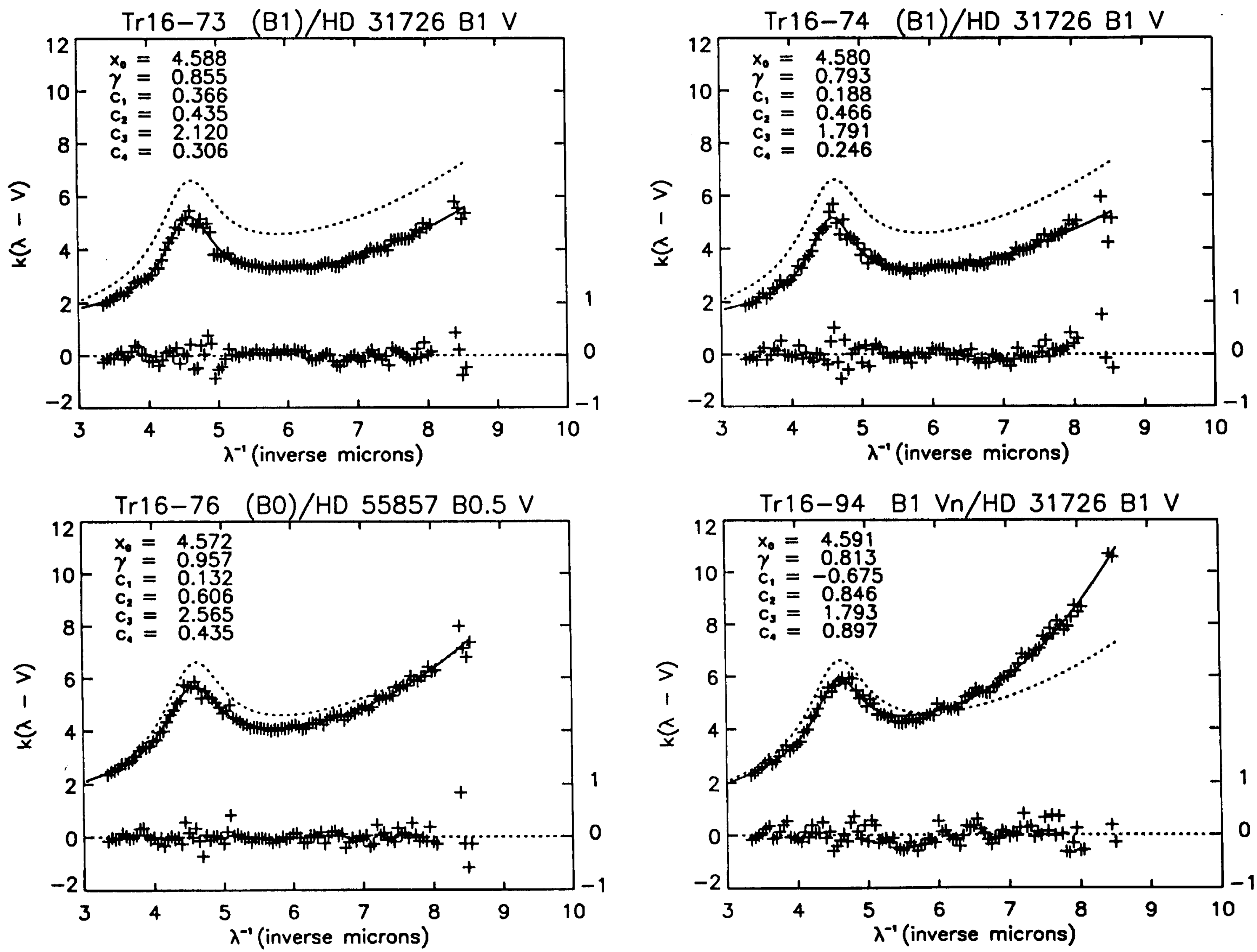

Tr16−73 (B1)/HD 31726 B1 V
x₀ = 4.588
γ = 0.855
c₁ = 0.366
c₂ = 0.435
c₃ = 2.120
c₄ = 0.306
Tr16−74 (B1)/HD 31726 B1 V
x₀ = 4.580
γ = 0.793
c₁ = 0.188
c₂ = 0.466
c₃ = 1.791
c₄ = 0.246
Tr16−76 (B0)/HD 55857 B0.5 V
x₀ = 4.572
γ = 0.957
c₁ = 0.132
c₂ = 0.606
c₃ = 2.565
c₄ = 0.435
Tr16−94 B1 Vn/HD 31726 B1 V
x₀ = 4.591
γ = 0.813
c₁ = −0.675
c₂ = 0.846
c₃ = 1.793
c₄ = 0.897
k(λ − V)
λ⁻¹ (inverse microns)

Fig 2 (cont)

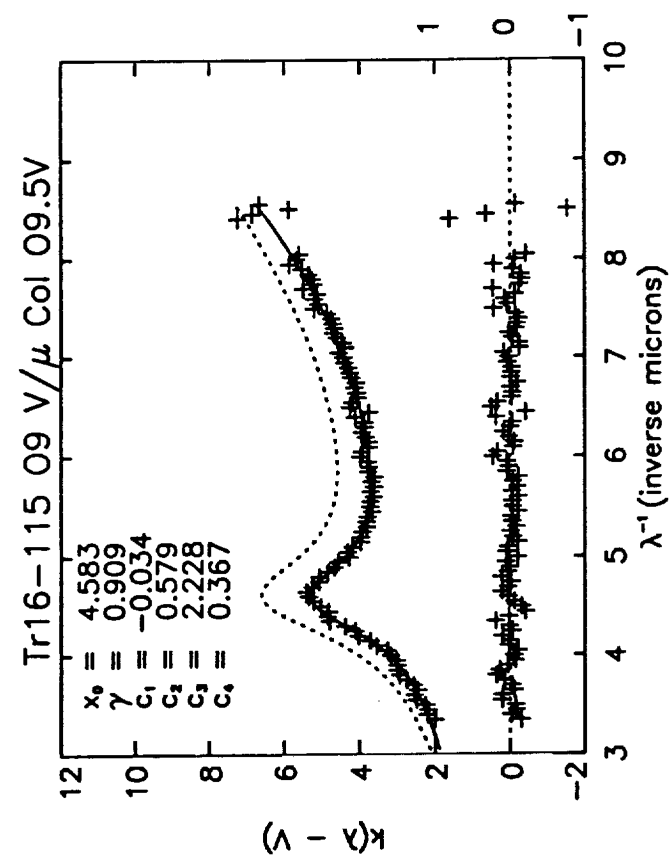

Tr16−115 O9 V/μ Col O9.5V
x₀ = 4.583
γ = 0.909
c₁ = −0.034
c₂ = 0.579
c₃ = 2.228
c₄ = 0.367
k(λ − V)
λ⁻¹ (inverse microns)

Fig 2 (cont)

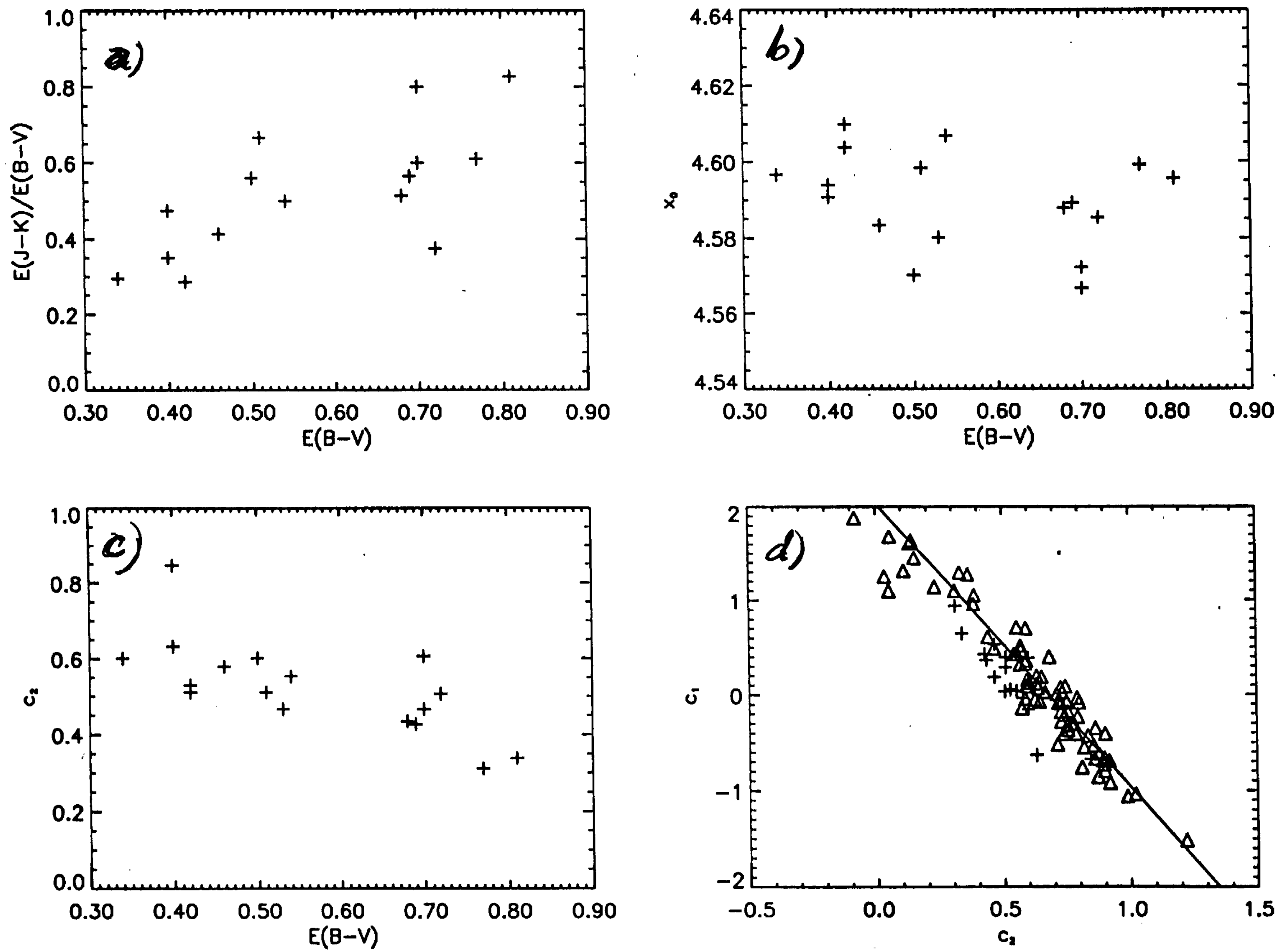

a)
b)
c)
d)
E(J−K)/E(B−V)
E(B−V)
x_0
c_2
c_1
0.30 0.40 0.50 0.60 0.70 0.80 0.90
0.0 0.2 0.4 0.6 0.8 1.0
4.54 4.56 4.58 4.60 4.62 4.64
−2 −1 0 1 2
−0.5 0.0 0.5 1.0 1.5

Fig 3

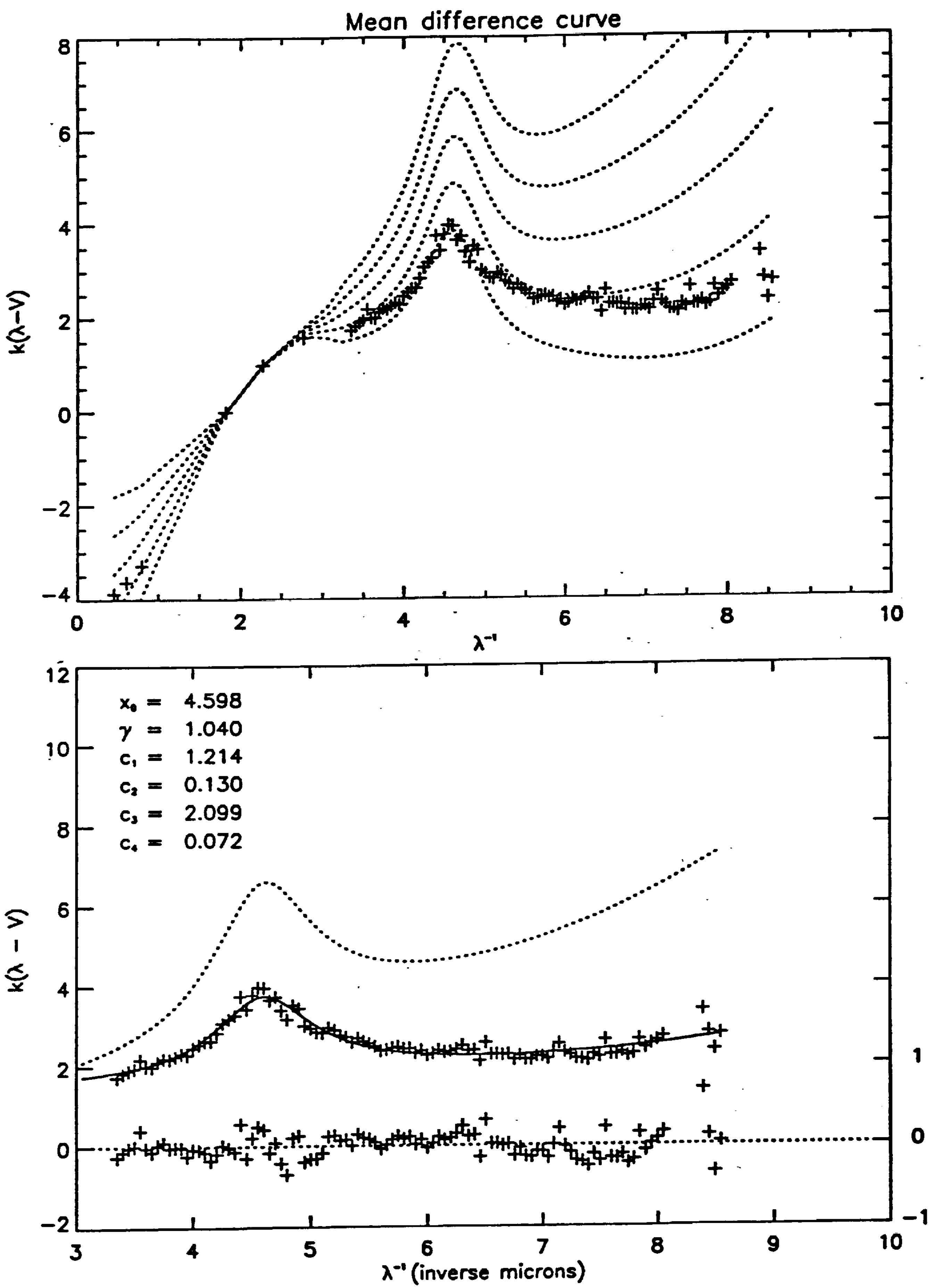

Mean difference curve
8
6
4
2
0
−2
−4
k(λ−V)
0
2
4
6
8
10
λ⁻¹
12
10
8
6
4
2
0
−2
k(λ − V)
x₀ = 4.598
γ = 1.040
c₁ = 1.214
c₂ = 0.130
c₃ = 2.099
c₄ = 0.072
1
0
−1
3
4
5
6
7
8
9
10
λ⁻¹ (inverse microns)

Fig 4

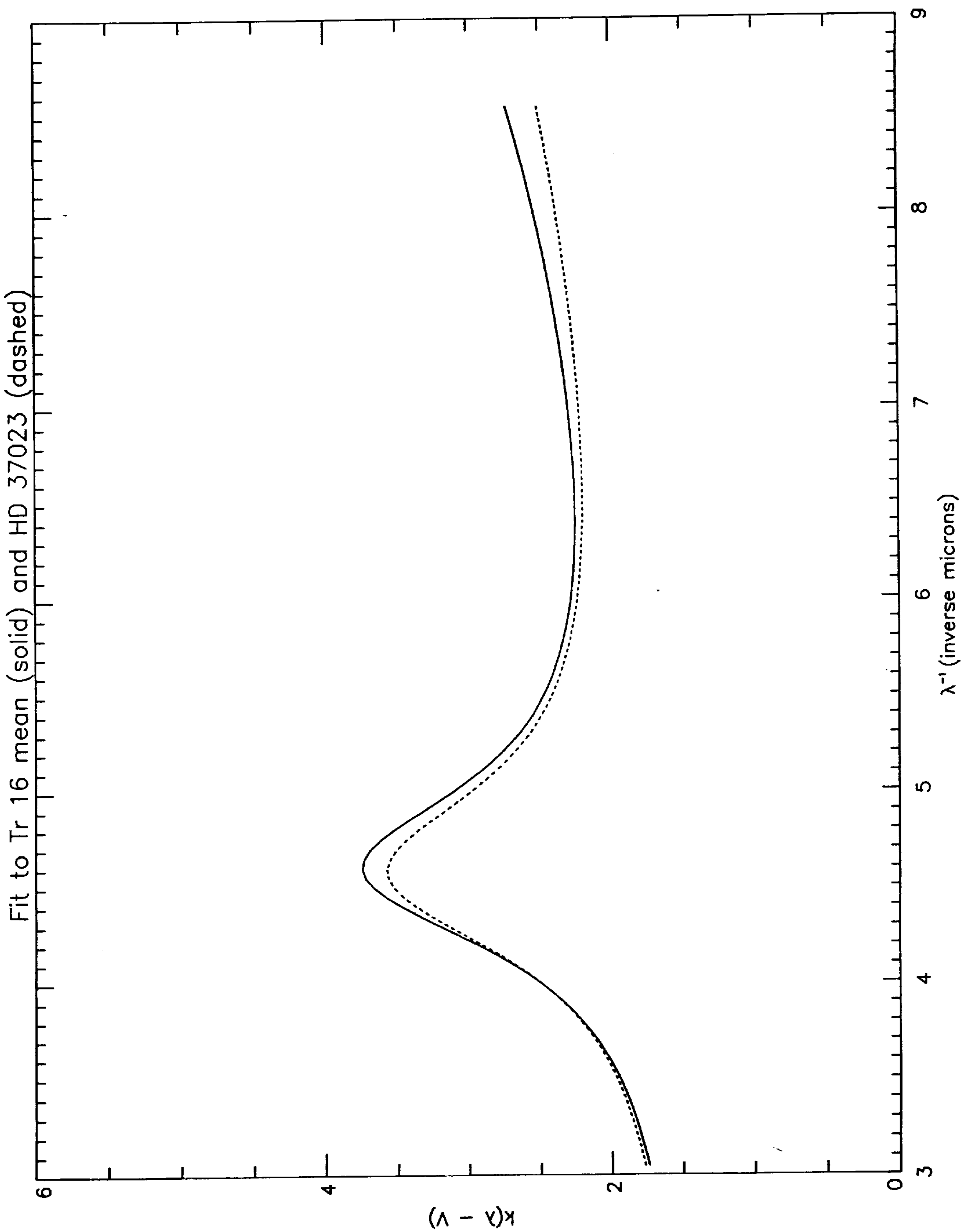

Fit to Tr 16 mean (solid) and HD 37023 (dashed)
k(λ − V)
0
2
4
6
λ⁻¹ (inverse microns)
3
4
5
6
7
8
9

Fig 5

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15. Supplementary Notes

16. Abstract

I have performed an analysis of the UV extinction by dust along the line of sight to the young open cluster Tr 16. The observed curves are parameterized in order to extract quantitative information about the structure of the curves. Furthermore, by constructing differential extinction curves, obtained by differencing curves for stars which lie within a few arc seconds of each other on the sky, I was able to obtain a curve which is free of the effects of foreground extinction, and represents the extinction by the dust in the Tr 16 molecular cloud. I then show that this curve is nearly identical to one due to dust in the Orion molecular cloud. This result shows that dust in the Carina arm exhibits the same behaviour as that in the local arm.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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